The Effects of Mild Traumatic Brain Injury on Theta Synchronization and Working Memory: A Spectral Analysis

An Honors Thesis (PSYS 499)

by

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Abstract

The current study investigated theta synchronization in the context of mild traumatic brain injury (mTBI) and working memory using archival baseline electroencephalographic (EEG) and operation-span (OSPAN) data. Data was initially obtained using BioSemi software and processed using MatLab. It was hypothesized that greater theta synchronization would be associated with better working memory performance and history of mTBI would be inversely related to both theta synchronization and working memory performance. No significant effect of history of injury on frontotemporal theta synchronization or working memory was found, however, future directions may analyze theta synchronization in parietal clusters, as well as consider potential improvements in concussion reporting methodology.

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Process Analysis Statement

Electroencephalographic, or EEG, research has become increasingly interesting to me during my time at Ball State University as I have been involved with a number of projects examining topics including but not limited to: anxiety, stress, and even music. As someone who is interested in the field of neuropsychology, including brain injury, as well as someone who enjoys sports and has experienced a concussion myself, I began wondering what types of brain wave patterns might be observed for students who had undergone this common type of injury. I was aware of the relative ease of obtaining subsequent concussions after having a previous injury, both from personal experience and hearsay, and I wondered if some of the underlying neural mechanisms that had been explored in previous projects in our lab might have a role in brain injury and recovery.

When students choose to participate in our studies, we ask that they fill out a health survey, and information about concussion and injury history is gathered, along with other items. That being said, this data would be available to use archivally through these other studies after working with the Institutional Review Board to gain permission to use it for this purpose. This process proved a learning experience as I gained further knowledge of these procedures.

I was involved with data collection and processing for both of the other studies from which my data was collected, and this has been an incredible learning experience. I have learned to use computer software to filter electrical interference and separate muscle artifacts from neurological data. I have also learned to work with participants as they enter our lab and instruct them on procedures for our studies, which has honed both my scientific and interpersonal skills. It has been enjoyable to share this area of study with participants in our lab, as they become familiar with EEG technology.

This project is in many ways a culmination of my undergraduate research experience and while it has been rewarding, it has also presented its share of challenges, as EEG data must first be collected, pre-processed, and cleaned before it can be statistically analyzed. For example, I have spent a significant amount of time working with sometimes-challenging computer software, attempting to decipher complex error messages, and separating blinks from brain activity. Through this, I have increased my knowledge of electroencephalographic technology, a tool I personally believe has a bright future in the field of neuropsychology, as you will read more about in my manuscript. I am both intrigued and encouraged by the literature I have read in the construction of this thesis. I think my project provides interesting insight into potential connections between a prominent aspect of modern-day sports medicine and neuropsychological principles.

The Effects of Mild Traumatic Brain Injury on Theta Synchronization and Working Memory: A Spectral Analysis

Mild traumatic brain injury (mTBI), often colloquially referred to as *concussion*, is an emerging area of interest, specifically within the field of neuropsychology. A variety of causes can account for its etiology as well as the severity of individual cases, and prognoses may vary accordingly. However, there remains much ambiguity surrounding the diagnosis and prognosis of mTBI. As we become increasingly aware of the phenomenon, we must consider not only its immediate clinical significance, but also potential long-term repercussions in order to establish a more comprehensive treatment plan for affected individuals. Evidence of neuropathological mitigation following electrically-based treatments suggests possibility for improving understanding of and treatment for mTBI in this context (Pevzner, Izadi, Lee, Shahlaie, & Gurkoff, 2016).

Neural Frequency Bands and Synchronization Efficiency

One way to explore this phenomenon is by recording brain activity using electroencephalogram (EEG). Brain activity as recorded on EEG is primarily divided into four types of bands (Nuwer, 1988). Delta activity generally encompasses that which falls between 0-4 Hz, theta between 5-7 Hz, alpha between 8-13 Hz, and beta 14 Hz or higher, however, these bands are sometimes differentiated with other conventions, but regardless provide a basis for conceptualization (Nuwer, 1988). Lakatos and colleagues (2008) discussed evidence for the idea that synchronized neural firing patterns improve neuronal communication efficiency, which may decrease reaction time for system-related tasks (Lakatos, Karmos, Mehta, Ulbert, & Schroeder, 2008).

As discussed in a review of the literature by Klimesch (1999), theta oscillations have been shown to be integrally associated with memory processes, specifically for their role in the

process of encoding novel information. Raghavachari and colleagues (2001) recorded theta activity during the Sternberg working memory task via cortical electrodes and observed increased theta activity during the task (Sternberg, 1966; Raghavachari et al., 2001). Fuentemilla, Penny, Cashdollar, Bunzeck, and Düzel (2010) demonstrated the role of theta in the replay component of maintaining information in working memory.

In a review of the literature, Fell and Axmacher (2011) emphasized the importance of neural synchronization for the efficiency of neural networks involved in memory processes. Similarly, Lisman (2010) reviewed various findings (e.g., Rutishauser, Ross, Mamelak, & Schuman, 2010) that support the idea that theta and gamma oscillations together help organize encoding patterns, which would then mediate the efficiency of working memory. Thus, the literature suggests that theta synchronicity should be associated with an increase in working memory performance.

Mild Traumatic Brain Injury

Traumatic brain injury has been shown to disrupt brain activity in rats in regions associated with memory, specifically the hippocampus, resulting experimentally in lower theta power in rats that had undergone brain injury (Fedor, Berman, Muizelaar, & Lyeth, 2010). Reeves, Lyeth, Phillips, Hamm, and Povlishock (1997) measured inhibition in the hippocampus and dentate gyrus after injury in rats and found patterns that may help explain changes following injury. While animal models such as these often lend access to readily exploring acute effects of experimenter-induced traumatic brain injury, to my knowledge there is comparatively limited knowledge surrounding chronic effects of brain injury, specifically the mild type. In their review of current evaluation and treatment practices of mTBI, Prince and Bruhns (2017) referenced reports from both the Centers for Disease Control and Prevention and the World Health Organization that estimated a majority (75-90%) of brain injuries seen in emergency services

would be classified as mild, and some individuals may not visit the emergency room in response to their injury, making these types of injuries potentially more common than statistically evident (Centers for Disease Control and Prevention [CDC], 2003; World Health Organization [WHO], 2006; Jagoda et al., 2009). Additionally, Murray, Murray, and Robson (2015) call for a change in sports culture when it comes to concussions, referencing literature that highlights the glaring lack of attention and recognition given to concussions when they occur (Langlois, Rutland-Brown, & Wald, 2006). Thus, based on such literature, it appears that the majority of brain injuries are not severely traumatic instances with necessarily overt effects, but rather more mild instances of brain injury, for which the effects may be less disruptively obvious. While some report being symptom-free soon after injury, post-concussive syndrome, or PCS, is one explanation for extended pathology associated with experiencing mTBI (Ryan & Warden, 2003).

In a team setting, athletes often undergo a series of tests and evaluations of symptomology to determine readiness to return to play, however, some subtle symptoms such as fatigue may overlap with other causes and may not be indicative of injury; additionally, a baseline measure is not always available (d'Hemecourt, 2011; Hunt, Paniccia, Reed, & Keightley, 2016). Interestingly though, some patients have a more difficult time recovering from subsequent concussions and may experience more severe long-term effects from a series of concussions over time (Centers for Disease Control and Prevention [CDC], 2017). Additionally, literature shows that there is a time window separate from improved symptomology for which the brain is metabolically more susceptible to further injury (Vagnozzi et al., 2008). Thus, it may be that overall symptomology is not a reliable enough standalone indicator of neurological status. The need to further conceptualize neurophysiological and neuroelectric correlates of injury presents an opportunity for the fields of sports medicine and neuroscience to expand knowledge

and education on this topic. Thus, it is imperative to explore the underlying neural mechanisms that may be affected in order to continue to develop more comprehensive treatment.

Working Memory

A meta-analysis by Frencham, Fox, and Maybery (2005) discusses memory as one focus of neuropsychological deficit assessment in individuals with mTBI, concluding that memory deficits appear to be strong directly after injury but generally fade with time, however, they review the potential lack of certain test sensitivity to mTBI (e.g., Cicerone, 1997; Bernstein, 1999) as well as methodological flaws that may contribute to the need for additional research in the post-acute stage. Thus, with much ambiguity surrounding the exploration of post-acute effects, examining baseline theta power in conjunction with performance on a working memory task may provide insight for this type of research. Interestingly, electrically stimulating regions associated with memory after injury using theta-burst stimulation, demonstrated by Sweet and colleagues (2014) by using electrodes on the rat fornix and hippocampus, was shown to positively impact performance on a maze task reflective of learning and memory functioning (Sweet, Eakin, Munyon, & Miller, 2014). Thus, perhaps by aiding in theta phase-locking through electrical stimulation, these cognitive processes exhibit improvement.

Thériault and colleagues (2011) analyzed the sustained posterior contralateral negativity (SPCN) waveform during a task indicative of visual working memory storage (Thériault, Beaumont, Tremblay, Lassonde, & Jolicoeur, 2011). They found that even though differences in the SPCN waveform varied for individuals with extensive concussion history and the waveforms were associated with estimated visual memory capacity, there was no significant difference in that estimate of capacity between groups, suggesting that neurophysiological differences existed, yet performance deficits were not obvious (Thériault et al., 2011). Kumar, Rao, Chandramouli, and Pillai (2009) measured connectivity during both visuospatial and verbal working memory

tasks and noted diminished connectivity while using working memory for participants with mTBI, attributing the deficits to the subcortical damage to white matter during injury as discussed by Nuwer and colleagues (Nuwer, Hovda, Schrader, & Vespa, 2005). Interestingly though, Nuwer and colleagues (2005) report that such deficits would not be expected to be observed chronically. However, the current study aims to explore the possibility of electrical desynchronization as a contributor to subsequent concussion sensitivity (Nuwer et al., 2005; CDC, 2017).

Hypotheses

In the current study, it was hypothesized that increased working memory performance would be associated with increased theta synchronization, or higher theta power, due to the role of theta phase-locking in the replay component of working memory (Fuentemilla et al., 2010). Because of the disruptions in theta-based systems associated with traumatic brain injury demonstrated by Fedor and colleagues (2010) and Reeves and colleagues (1997), it was hypothesized that increased history of mTBI, or concussions, would similarly be associated with theta desynchronization, or lower theta power, thus hypothesizing an inverse relationship between history of mTBI and theta synchronization and a direct relationship between theta synchronization and performance on a working memory task.

Method

Participants

In the studies from which data was obtained archivally, participants were recruited through the participant pool at Ball State University. This data initially functioned as baseline recordings for other studies, including one involving trait anxiety (Ward et al., 2018) and one involving reading comprehension (Smith, S. L., *unpublished master's thesis*). For the first study, participants had completed an anxiety inventory prior to the EEG session, and a baseline

recording was collected prior to participation in tasks measuring executive function (Ward et al., 2018). The participants cleared for participation in this particular study had to meet criteria for either high or low trait anxiety, determined by a pre-screening survey. Additionally, data was obtained from another student's master's thesis (Smith, S. L., *unpublished master's thesis*) examining reading comprehension, working memory performance, and other variables, in which a baseline EEG recording was obtained prior to completion of a reading task. This occurred either before or after the administration of cognitive tasks including operation-span (OSPAN), which measures working memory and from which data will also be incorporated into the current study, and an antisaccade task, depending on the prescription of the counterbalance (Turner & Engle, 1989; Smith, S. L., *unpublished master's thesis*). Conversely, there was no pre-screening criteria for this study (Smith, S. L., *unpublished master's thesis*).

Archival data from a total of 71 participants was analyzed, of which 15 reported a history of injury (21.1%). 87.3% of participants identified as White or Caucasian, 2.8% Black or African-American, 1.4% Hispanic or Latinx, 1.4% Asian, and 5.6% consisted of multiracial identities. Participants indicated their sex as 56.3% female and 42.3% male. There was an option provided for "other," but no participants indicated this answer. Participants were aged 18-25, and a majority (74.6%) were either 18 or 19 years old (M = 19.06, SD = 1.313).[1]

Materials

EEG data was obtained using BioSemi software and a 64-channel electrode cap with reference electrodes EXG4, EXG6, EXG7, and EXG8. Participants gave informed consent and a precautionary allergy test of the SignaGel® used for electrical conductance was administered to

[1] Missing percentages may be attributed to unavailable demographic data for select participants, as participation was voluntary.

ensure participant safety. The OSPAN task was experimenter-administered using E-prime software to advance through the items along with pen and paper for the participant and experimenter to record words remembered and math accuracy, respectively. MatLab computer software was used to clean and spectrally analyze EEG data. See appendices for materials used in these studies.

Procedure

After setup, participants were shown their excess movements such as jaw clenching on a computer screen prior to recording in order to minimize additional EEG artifacts. Participants were then asked to remain still, minimizing the previously shown movements and assuming a relaxed state with opened eyes, while experimenters entered the control room to begin recording resting brain activity. During one of the studies (Ward et al., 2018), resting brain activity was recorded for three minutes. During the other (Smith, S. L., *unpublished master's thesis*), resting brain activity was recorded for four minutes. Data was then saved for later processing. The OSPAN working memory task was experimenter-administered as part of the study conducted by Smith (Smith, S. L., *unpublished master's thesis)* and was counterbalanced with the reading and antisaccade tasks also involved in the study. Participants were asked to read a math equation aloud, answer yes or no in regard to its accuracy, and read a word aloud following the equation, attempting to remember as many of these words in a given trial as possible (Smith, S. L., *unpublished master's thesis).*

The data used from Ward et al. (2018) was pre-processed and thoroughly hand-cleaned for artifacts using MatLab before extracting theta from both left and right frontotemporal clusters. The data used from Smith (*unpublished master's thesis*) was similarly pre-processed and initially hand-cleaned using MatLab, but underwent independent component analysis (ICA) as part of the cleaning process. It was then spectrally analyzed and theta at 4-8 Hz was extracted for

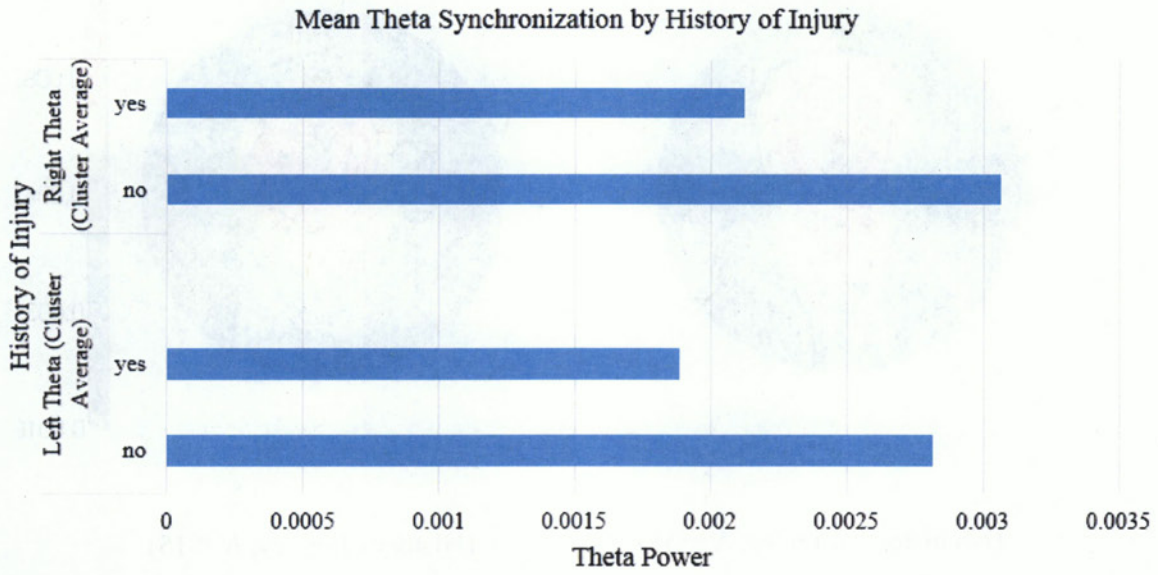
the frontotemporal clusters. Electrode sites analyzed included: FT7, FC5, FC3, T7, C5, C3, F7, F5, F3, and AF7 in the right hemisphere and their respective counterparts in the left hemisphere: FT8, FC6, FC4, T8, C6, C4, F8, F6, F4, and AF8. Working memory data in the form of behavioral results from the scored OSPAN task was additionally obtained from the study by Smith (*unpublished master's thesis*).

Results

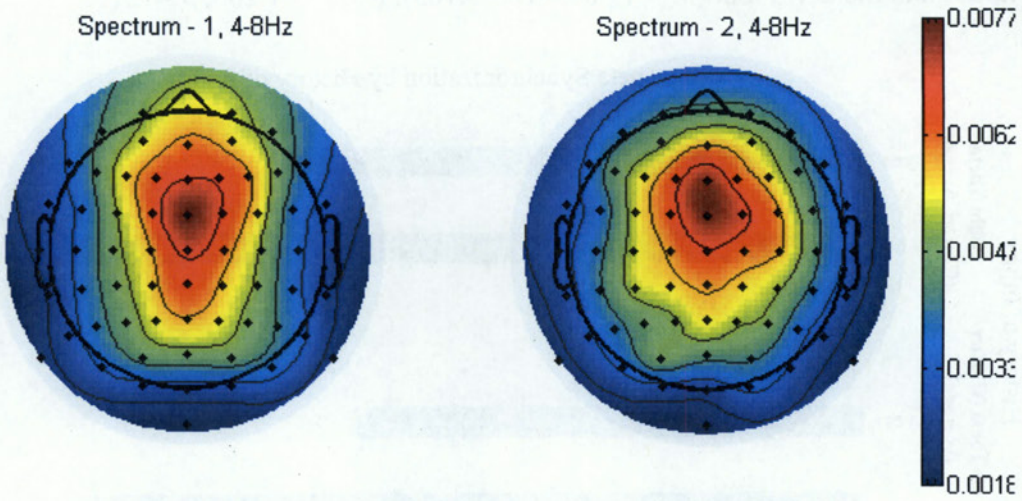
Theta Desynchronization, Working Memory, and History of Injury

A mixed ANOVA examining the between participant effects of history of injury (0 = no injury; 1 = any mTBI or head trauma mentioned) on within participant (right and left frontotemporal theta) brain activity revealed no significant effects of injury on overall brain activity: $F(1, 69) = .971$, $p = .328$. Furthermore, no significant interaction of injury on left and right theta were found: $F(1,69) = .002$, $p = .969$. An independent samples t-test was conducted to determine if group differences existed between individuals with and without a history of injury in terms of performance on the operation-span (OSPAN) task. No significant difference in OSPAN scores (relative) was found between individuals with a history of injury ($M = 22.20$, SD

= 4.550) and those without (M = 19.07, SD = 5.163); $t(31)$ = -1.266, p = .215.



The following topographical maps depict theta power between participants without a history of injury and participants with a history of injury. One dataset had to be excluded due to incompatibility with the computer software. In the second group, theta power appears to be distributed slightly differently than in the first group, with apparently lower theta power in the frontal lobe and a more localized rather than diffuse distribution of theta. However, it is unknown as to whether real differences exist, as future analyses need to statistically compare these electrode sites.

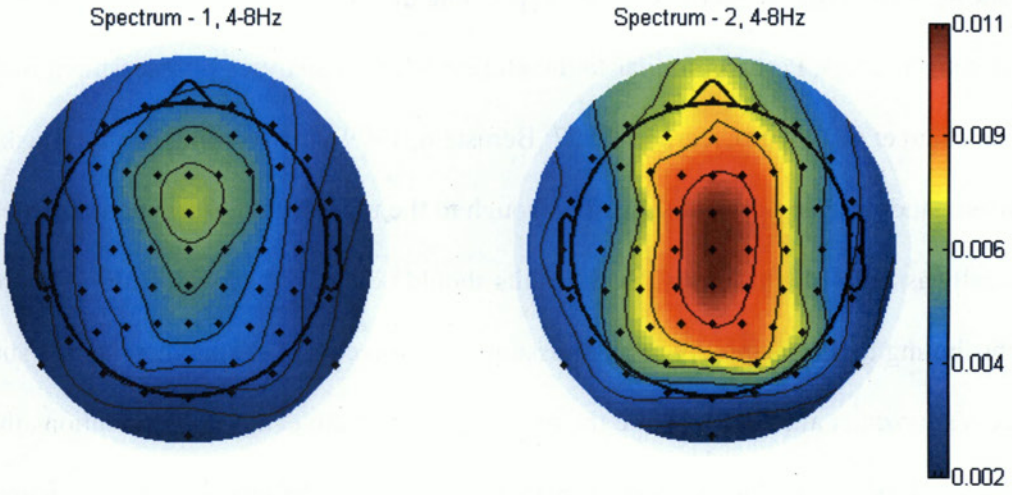


(No history of injury; $N = 55$) (History of injury; $N = 15$)

Results: Post-hoc Analyses

Theta Synchronization and Age

To determine if demographic differences existed, post-hoc analyses compared theta power with age. After conducting spectral analysis by extracting theta from frontotemporal electrode sites using MatLab software, an exploratory Pearson's R correlational analysis was run examining the relationship of left theta, right theta, and participant age. The result was a near-significant correlation for right theta and age, $r(65) = .216$, $p = .08$, and less significant for left theta and age, $r(65) = .169$, $p = .172$. The following topographical maps depict theta power between the younger participants ($N = 59$) and older participants ($N = 7$). One dataset from the younger group had to be excluded due to incompatibility with the computer software.



Age 18-20 ($N = 59$) Age 21-25 ($N = 7$)

*Note: This data is demonstrated visually in terms of two separate groups, though statistically represented with a correlation.

Sex Differences

To determine whether males and females were equally likely to report a history of injury, a Pearson chi-square test of goodness of fit was used. The result indicated that there is no relationship between sex and likeliness to report a history of injury, χ^2 (2, $N = 71$) = 2.336, p = .311.

Discussion

The current study aimed to lend insight to current conceptualization of mTBI by exploring the effects of history of brain injury, including mild injury, or *concussion,* on theta synchronization and working memory performance. It was hypothesized that participants reporting a history of injury would demonstrate significantly lower theta power, as well as weaker performance on a working memory task (OSPAN). However, participants reporting a history of injury were not significantly more likely to exhibit decreased theta synchronization or

working memory deficits. However, it is possible that different methodology could reveal different findings. Perhaps similar to the aforementioned analyses of assessment measures (Frencham et al., 2005; Cicerone, 1997; Bernstein, 1999), the working memory task in the current study was simply not sensitive enough to the types of long-term neural patterns that are actually associated with injury. Such results should be interpreted with caution in order to avoid contributing to the seemingly popular assumption of recovery despite heightened susceptibility (see Vagnozzi et al., 2008). While the review by Frencham et al. (2005) mentions that some memory deficits may fade with time, perhaps the obvious deficits are being measured rather than more subtle changes. For example, the study by Thériault et al. (2011), emphasizes that even when specific neurophysiological differences in the SPCN were evident, participants performed equally on the given working memory task.

The nearly-significant correlation between age and theta synchronization is consistent with the literature on myelination, as reviews of the literature conclude that neuronal white matter continues developing even after most of the brain has matured, improving connectivity with age (Casey, Jones, & Hare, 2008). Thus, a positive relationship between theta synchronization and age would make sense given a more connected and efficient brain.

Interestingly, Zappasodi, Marzetti, Olejarczyk, Tecchio, and Pizzella (2015) found that across participants aged 16-85, neural connectivity was best described mathematically using a parabola, as synchrony was found to increase during young adulthood and decrease during late adulthood. Though the current study involves considerably less age variability, it seems that some of the neural desynchronization that occurs in late adulthood may be similarly occurring in reverse during development. These patterns may, in turn, have implications for cognitive efficiency and even though the results from the OSPAN task did not vary with age or theta

power, future research should consider the applicability of such differences to other measures reflecting different components of cognitive efficiency.

If future research does identify a significant trend in neural frequency patterns, this may have implications for injury rehabilitation, for example, through neurofeedback. Neurofeedback utilizes operant conditioning to help train patients to change their spectral ratios via the comparison of neurotypical and atypical spectral ratios and subsequent implementation of specific therapeutic activities such as, for example, a neural task-specific computer game (Evans & Abarbanel, 1999). If specific neural frequency patterns can be identified as significantly atypical and associated with mTBI, treatment other than simple rest and recovery may be available to help mitigate some of the symptoms of injury, including post-concussion syndrome.

Strengths and Limitations

The current study used baseline, or at rest, measures for both groups. Thus, though participants were participating in different studies that involved various tasks, all recordings used for this study were at-rest measures. While this was beneficial in maintaining consistency across archived data, it also presents a limitation in that the during-task theta was not compared in the current study. Limitations of the current study also include reliance on self-report for concussion measurement. However, it could be argued that this is a limitation for concussion research in general, as improving concussion diagnostic measures could help mitigate ambiguity relating to concussions in the field of medicine overall.

Regardless, this study utilized a rudimentary questionnaire approach to determining history of injury, and self-report bias may have influenced the results. Additionally, it is possible that participants could have failed to report a concussion due to a lack of knowledge of concussion symptomology, as the current study did not obtain medical or athletic records but instead relied on participant self-report. As Murray et al. (2015) points out, concussion has long

been regarded as "a benign condition part and parcel of sporting activity" (Murray et al., p. 75). Thus, it could be that participants disregarded concussion symptomology at the time of injury and thus, failed to recollect and report it.

Group size presents another limitation, as well as the fact that only one participant in the older group for the topographical maps reported a history of injury. Thus, there could be potential for a confounding variable of age in terms of the near-significant correlation ($p = .08$) with history of injury. Replications of this study should be conducted with a more equal representation of injury in terms of age, if possible.

Another limitation of the study involves the conduciveness of EEG equipment to certain hairstyles, rendering it difficult to obtain an ethnically diverse sample. Geographic restriction due to the fact that all data was obtained at a single location may also be a limitation. Another limitation is time since injury. Some research suggests that differences change and even resolve with time, for example, as mentioned in a review by Nuwer and colleagues (2005), e.g. Koufen & Dichgans (1978). Thus, it may be helpful to consider time since injury in future directions.

Future Directions

Future directions include the potential addition of more participant data. Future studies should consider the implementation of a concussion inventory with more distinct categories and better-defined criteria for injury reporting. A regression analysis comparing multiple levels of injury history to theta synchronization and working memory performance may help differentiate effects of varying levels of concussion severity. Additionally, it would be interesting to record and analyze theta synchronization during task performance. Lastly, statistically comparing data from a spectral analysis of parietal frequencies and thus, considering data from different

electrode sites other than those from frontotemporal regions, might be helpful in identifying potential regional differences in synchronization.

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Appendix A

Informed Consent for EEG Portion of Study: Ward et al. (2015)

Informed Consent

Title: Neural Correlates of Attentional Control Theory in High Trait Anxious Individuals

Project Description: The purpose of this research is to examine patterns of brain activity in relation to performance on a task that measures executive functions. Brain activity will be assessed with electroencephalography (EEG), a well-established measure used in medical studies for people with known or suspected neurological disorders such as seizures. EEG works by recording the electrical activity of a person's brain. Later, we will take these recordings and look at the specific activity of your brain in response to the tasks you are asked to perform.

Methods and Procedure: Your responses on the pre-screening portion of this study have made you eligible to be invited to the laboratory for the second portion of the study. During this portion, you will first have an EEG reading taken while you perform two computerized tasks. This procedure is painless and should cause no discomfort aside from a tight cap being placed on your head. The EEG process involves us placing and taping electrodes on your face and a cap being placed on your head. Gel will be placed in holes in the cap and will get into your hair and will also be placed onto the facial electrodes and thus will get onto your face. The gel is non-toxic and washes out of your hair easily with a shower. You will also be given an opportunity to wash your face in the restroom when the experiment is complete. The EEG preparation process should take about 30 minutes. After you have had the EEG cap placed, you will complete two separate tasks. One task will require you to place a card in one of four piles based on similar characteristics. The rule for correctly placing the card into the appropriate pile changes, and you must switch strategies based on either the shape, color, or number of objects on the card. The other task will require you to respond based on the direction of a target stimuli. Additional stimuli will be presented in either the same, opposite, or neither directions. You must respond based on the direction of the target stimulus. This process will take up to 60 minutes to complete, and we will be recording your brain activity while you do this task. Note that we cannot read your mind or thoughts from recording this activity; we merely record the electrical responses of neurons, the tiny cells in your brain, to the information on the screen. The information we record will tell us about how fast your brain is able to perform this task and transfer information between the two hemispheres. While you perform the tasks, we will be in the next room recording your brainwaves and watching you on a video camera. We will not record you with the camera – it is merely a precaution to make sure you do not run into trouble while completing the experiment. This portion of the study should take no longer than 90 minutes to complete. Attachment of the EEG equipment will take about 30 minutes. Next, completion of both tasks will take at most 30 minutes to complete. Finally, detaching the EEG equipment will take 30 minutes at most.

Requirements of participation: In order to participate in this portion of the study you must be at least 18 years of age at the time of the study. In addition, you must have met the required criteria on both the medical questionnaire, and trait anxiety questionnaire. These requirements

include meeting a specific level of trait anxiety, and having no history of concussions, seizures, or medications that may affect serotonin (e.g. Prozac) and benzodiazepines (e.g. Alprazolam).

Data Confidentiality: Your responses in this study will be confidential. That is, there is no way that your responses will be linked to your identity. If you choose to participate in this study you will need to sign this consent document. However, the consent documents are kept separate from the experimental data and hence your responses will be confidential. Your responses will be transferred into a computerized data set that will be stored on the primary investigator's computer, which is password protected. In the data set, no identifying data will be collected or recorded. Data involving task performance will be compared with other participants via statistical analyses. Data involving EEG frequencies will also be compared with other participants via statistical analyses. The data will be kept for three years and then destroyed.

Participation is Voluntary: Your participation in this research project is voluntary and will not affect your relationship with your psychology professor or Ball State University. You can withdraw from the project at any time without negative consequences. Upon completion of this portion of the study, you will receive $5 and 1.5 SONA credits for participating in this study. Please feel free to ask questions of the researcher before signing the Informed Consent Form as well as at any time during the study.

Exclusion Criteria: Prior neurological damage (i.e. concussions), the use of benzodiapines (e.g. Alprazolam), use of SSRIs (e.g. Prozac), and use of SNRIs (e.g. Duloxetine). Participants who did not meet the designated anxiety criteria will also be excluded.

Potential Risks: There are no anticipated risks to participating in this portion of the study other than discomfort associated with having a cap which is relatively tight placed on your head and from having electrodes taped gently to your face with medical adhesive. If at any time you express discomfort with the EEG process, the examiner will discontinue testing immediately.

You will be responsible for the costs of any care that is provided [note: Ball State students may have some or all of these services provided to them at no cost]. It is understood that in the unlikely event that treatment is necessary as a result of your participation in this research project that Ball State University, its agents and employees will assume whatever responsibility is required by law.

Questions: Please call Richard Ward, Principle investigator, at (859) 536-0507, with any questions. For questions about your rights as a research subject, please contact Director, Office of Research Integrity, Ball State University, Muncie, IN 47306, (765) 285-5070, irb@bsu.edu.

Incentives provided to participants of this portion of the study include $5 for participation time. There will be no financial expenses to participants in the study.

I have read and understand the above information and agree to participate in the research project entitled, Neural Correlates of Attentional Control Theory in High Trait Anxious Individuals, study.

_____ _____

Signature Date

Researcher Contact Information

Principle Investigator
Richard Ward
M.A. Clinical Pscyhology
Ball State University
rtward@bsu.edu
859-536-0507

Faculty Advisor
Stephanie Simon-Dack, PhD.
Professor of Psychological Science
Ball State University
slsimondack@bsu.edu
765-285-1308

Appendix B

Informed Consent: Smith, S.L., *unpublished master's thesis*

Informed Consent

Study Title: "An Electrophysiological Investigation of How the Brain Reads"

Study Purpose and Rationale: The purpose of the study is to examine the relationship between cognitive processes and reading comprehension using electroencephalography (EEG). Understanding non-fiction text may be associated with particular cognitive functions, so this study will explore the nature of how humans read.

Inclusion/Exclusion Criteria: Students must be at least 18 years old or older, a native English speaker to participate, and have normal or corrected-to-normal vision.

Participation Procedures and Duration: To participate in this study, you will need to provide consent for participating after reading this form. Additionally, in participating, we ask that you release your ACT-English, ACT-reading, or SAT-reading scores through a separate Family Education Rights and Privacy Act (FERPA) of 1974 form. Your test scores will be not be linked to your identity, as they will be de-identified. If you would do not wish to release your scores, you may continue participating in the study without doing so. During this study, you will then perform two cognitive tasks and a reading task. For the reading task specifically, your EEG will be recorded. This procedure is painless and should cause no discomfort aside from a tight cap being placed on your head and the experience of feeling mildly cold gel on your scalp. The EEG process involves us placing and taping electrodes on your face and a cap being placed on your head. Gel will be placed in holes in the cap, which will get into your hair. The gel will also be placed onto the facial electrodes and thus will get onto your face. The gel is non-toxic and washes out of your hair and off your face easily with a shower. You will also be given an opportunity to wash your face in the restroom when the experiment is complete. The EEG preparation process should take about 30 minutes. The entire experiment should take about two hours. During your completion of the tasks, we will be in the next room recording your brainwaves and watching you on a video camera. The cameras will not be recording you; this is a precaution to make sure you do not run into trouble while completing the experiment.

Note: we cannot read your mind or thoughts from recording this activity; we merely record the electrical responses of neurons, the tiny cells in your brain, and map that activity to the information on the screen. The information we record will tell us about what kind of processes your brain is performing while reading non-fiction text.

Disclosure of Alternative Procedures: If you are a PSYS 100 or MKG 300 student, you will receive two Ball State research credits for participating in this study. If for any reason you feel unable to continue the study procedure, you will still receive course credit for participating. Alternative studies and procedures are available if you do not want to participate in this study for course credit.

Data Confidentiality: Your responses in this study will be confidential. That is, your responses will not be linked to your identity. If you choose to participate in this study you will need to sign this consent document after you finish reading. However, all signed documents will be kept separate from your responses collected during this study.

All of your data collected from participating in the study will be confidentially transferred into a computerized data set located in the lab. In the data set, no identifying data/information will be recorded, in that your data will be coded with an arbitrary number and thus not associated with your identity.

Storage of Data and Data Retention Period: Data will be stored on a password protected computer and secure internal hard-drive, as well as a locked file cabinet for an indefinite amount of time. This confidential data will be kept indefinitely for scientific transparency and possible future use.

Risks or Discomforts: There are no anticipated risks to participating in the study other than discomfort associated with having a cap which is relatively tightly placed on your head and from having electrodes taped gently to your face with medical adhesive. If, at any time, you express discomfort with the EEG process, the examiner will discontinue testing immediately.

You will be responsible for the costs of any care that is provided. Note: Ball State students may have some or all of these services provided to them at no cost. It is understood that in the unlikely event that treatment is necessary as a result of your participation in this research project, law requires that Ball State University and its agents and employees will assume whatever responsibility (see information below for any contact information you may need).

Who to Contact Should You Experience Any Negative Effects from Participating in this Study: If you experience any negative effects from participating in this study, please contact the Ball State Counseling Center in Lucina Hall, 765-286-1736.

Benefits: There are no anticipated benefits.

Voluntary Participation: Your participation in this study is completely voluntary and you are free to withdraw your permission at any time for any reason without penalty or prejudice from the investigator. Please feel free to ask any questions for the investigator before or during the experiment.

IRB Contact Information: For one's rights as a research subject, you may contact the following: For questions about your rights as a research subject, please contact the Director, Office of Research Integrity, Ball State University, Muncie, IN 47306, (765) 285-5070 or at irb@bsu.edu.

Researcher Contact Information:

Primary Investigator:	Faculty Supervisors:	
Shelby Smith, BA	Stephanie Simon-Dack, PhD	Kristin Ritchey, PhD
Psychological Science	Psychological Science	Psychological Science
Ball State University	Ball State University	Ball State University
Email: slsmith16@bsu.edu	Email: slsimondack@bsu.edu	Email: karitchey@bsu.edu

Consent to Participate: Please fill out the lines below to consent to participate.

I, _____ (print name) have read and understand the above information and agree to participate in the research project entitled, An Electrophysiological Investigation of How the Brain Reads.

Signature: _____ Date: ____/____/____

[Approved IRB Protocol #: 1105589-1]

Appendix C

OSPAN Experimenter Copy

OSpan1 - KEY

S#_____

☒ = incorrect

****

Practice

a) ☐ No (aunt) ☐ Yes (bush)

b) ☐ Yes (corn) ☐ No (bear)

****

1) ☐ Yes (sea) ☐ No (class) ☐ No (paint)

2) ☐ No (cloud) ☐ Yes (pipe) ☐ Yes (ear) ☐ No (flame) ☐ No (bike)

3) ☐ No (bean) ☐ Yes (arm) ☐ No (ground)

4) ☐ Yes (hole) ☐ Yes (dad)

5) ☐ Yes (cave) ☐ No (back) ☐ No (hall) ☐ Yes (fern)

6) ☐ No (man) ☐ Yes (world)

7) ☐ No (bread) ☐ No (germ) ☐ Yes (dock)

8) ☐ No (game) ☐ Yes (nerve) ☐ No (wax) ☐ Yes (tin) ☐ Yes (church)

9) ☐ No (beach) ☐ No (card)

10) ☐ Yes (job) ☐ Yes (cone) ☐ No (brass) ☐ No (street)

Appendix D

OSPAN Participant Copy

Operation Span

S#_____

****

Practice

a) _____ _____

b) _____ _____

****

1) _____ _____ _____ _____ _____

2) _____ _____ _____ _____ _____

3) _____ _____ _____ _____ _____

4) _____ _____ _____ _____ _____

5) _____ _____ _____ _____ _____

6) _____ _____ _____ _____ _____

7) _____ _____ _____ _____ _____

8) _____ _____ _____ _____ _____

9) _____ _____ _____ _____ _____

10)_____ _____ _____ _____ _____

Appendix E

Health Survey (See Question 4 for Concussion Inventory)

Health Survey Participant Code:_____

Please answer the following questions to the best of your ability.

1. What is your age?

2. What is your sex?

   a. Male
   b. Female
   c. Other: _____

3. What is your ethnicity?

   A. American Indian or Alaska Native
   B. Asian
   C. Black or African American
   D. Native Hawaiian or Other Pacific Islander
   E. White
   F. Hispanic/Latino/Latina
   G. Other: _____

4. Have you ever hit your head and experienced a concussion? Yes No
   If yes, please explain and include the date and number of concussions experienced.

5. Have you ever experienced loss of consciousness? Yes No
   a. If yes, please explain and include the duration of loss of consciousness.

6. Since birth have you ever had any other medical problems? Yes No
   a. If yes, please explain.

7. Since birth have you ever been hospitalized? Yes No
   a. If yes, please explain.

8. Do you use tobacco (smoke and/or chew)? Yes No
   a. If yes, please explain.

9. Have you had any hearing problems? Yes No
   a. If yes, please explain.

10. Are you on any medications? Yes No
    a. If yes, please list them all including birth control.

11. Do you have any visual problems or impairment? Yes No
    a. If yes, please explain.

12. Do you have now or have you ever had any of the following? Check yes or no.

Diabetes	Yes	No
Neurological disorder	Yes	No
Brain disorder	Yes	No
Vascular disorder	Yes	No
Stroke	Yes	No
Learning deficiency or disorder	Yes	No
Reading deficiency or disorder	Yes	No
Attention-deficit disorder	Yes	No
Hyperactivity	Yes	No

If you checked yes for any of the items in question 13, please describe your diagnosis briefly.

Office of Research Integrity
Institutional Review Board (IRB)
2000 University Avenue
Muncie, IN 47306-0155
Phone: 765-285-5070

DATE: January 29, 2018

TO: Anna Allen

FROM: Ball State University IRB

RE: IRB protocol # 1146362-2
TITLE: The Effects of Minor Traumatic Brain Injury on Theta Synchronization
SUBMISSION TYPE: Amendment/Modification

ACTION: APPROVED
DECISION DATE: January 29, 2018
REVIEW TYPE: **EXEMPT**

The Institutional Review Board reviewed your protocol on January 29, 2018 and has determined the procedures you have proposed are appropriate for exemption under the federal regulations. As such, there will be no further review of your protocol, and you are cleared to proceed with the procedures outlined in your protocol. As an exempt study, there is no requirement for continuing review. Your protocol will remain on file with the IRB as a matter of record.

Exempt Categories:

	Category 1: Research conducted in established or commonly accepted educational settings, involving normal educations practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
XXXXX	**Category 2:** Research involving the use of educational test (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior
	Category 3: Research involving the use of educational test (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under category 2, if: (i) the human subjects are elected or appointed officials or candidates for public office; or (ii) Federal statute(s) require(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
XXXXX	**Category 4:** Research involving the collection of study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

	Category 5: Research and demonstration projects which are conducted by or subject to the approval of Department or agency heads, and which are designed to study, evaluate or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in methods or levels of payment for benefits or services under these programs.
	Category 6: Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed or (ii) if a food is consumed which contains a food ingredient at or below the level and for a use found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

Editorial Notes:

1. Can only use de-identified data.

While your project does not require continuing review, it is the responsibility of the P.I. (and, if applicable, faculty supervisor) to inform the IRB if the procedures presented in this protocol are to be modified or if problems related to human research participants arise in connection with this project. **Any procedural modifications must be evaluated by the IRB before being implemented, as some modifications may change the review status of this project.** Please contact (ORI Staff) if you are unsure whether your proposed modification requires review or have any questions. Proposed modifications should be addressed in writing and submitted electronically to the IRB (http://www.bsu.edu/irb) for review. Please reference the above IRB protocol number in any communication to the IRB regarding this project.

Reminder: Even though your study is exempt from the relevant federal regulations of the Common Rule (45 CFR 46, subpart A), you and your research team are not exempt from ethical research practices and should therefore employ all protections for your participants and their data which are appropriate to your project.

D. Clark Dickin, PhD/Chair
Institutional Review Board

Christopher Mangelli, JD, MS, MEd, CIP/
Director
Office of Research Integrity